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Trends and Variabilities in Rainfall and Streamflow: A Case Study of the Nilwala River Basin in Sri Lanka

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Abstract: Rainfall is one of the dominating climatic parameters that affect water availability. Trend analysis is of paramount significance to understand the behavior of hydrological and climatic variables over a long timescale. The main aim of the present study was to identify trends and analyze existing linkages between rainfall and streamflow in the Nilwala River Basin (NRB) of Southern Sri Lanka. An investigation of the trends, detection of change points and streamflow alteration, and linkage between rainfall and streamflow were carried out using the Mann–Kendall test, Sen's slope test, Pettitt's test, indicators of hydrological alteration (IHA), and Pearson's correlation test. Selected rainfall-related extreme climatic indices, namely, CDD, CWD, PRCPTOT, R25, and Rx5, were calculated using the RClimdex software. Trend analysis of rainfall data and extreme rainfall indices demonstrated few statistically significant trends at the monthly, seasonal, and annual scales, while streamflow data showed non-significant trends, except for December. Pettitt's test showed that Dampahala had a higher number of statistically significant change points among the six rainfall stations. The Pearson coefficient correlation showed a strong-to–very-strong positive relationship between rainfall and streamflow. Generally, both rainfall and streamflow showed non-significant trend patterns in the NRB, suggesting that rainfall had a higher impact on streamflow patterns in the basin. The historical trends of extreme climatic indices suggested that the NRB did not experience extreme climates. The results of the present study will provide valuable information for water resource planning, flood and disaster mitigation, agricultural operations planning, and hydropower generation in the NRB.

Keywords: Mann–Kendall test; Nilwala River Basin; indicators of hydrological alteration (IHA); Pettitt's test; rainfall trends

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1. Introduction

Climate is a key factor that affects environmental systems, socioeconomic conditions, and water resource availability [1]. The changes in rainfall patterns will directly affect streamflow and thereby domestic, agricultural, and industrial water needs [2]. Moreover, streamflow will also be affected by anthropogenic activities [2,3], such as land-use change, operation of dams and reservoirs, and direct water extraction from surface water and groundwater systems [4]. Hence, identifying and analyzing the long-term trends of meteorological and hydrologic data will be useful for water resource planning and management [5], flood protection and disaster mitigation [3,6], and agricultural operations [2].

Trend analysis will be valuable to eliminate errors in approximations in designing hydraulic structures under assumed fixed hydrometeorological variables [2].

Many studies in different geographic regions of the world were directed toward identifying trends and variabilities in rainfall and streamflow and their associated linkages [2,3,6–11]. Mersin et al. [10] stated that the variations in the frequency and magnitude of rainfall caused biotic and abiotic disturbances in the environment. Kastridis et al. [11] investigated the relationship between climate and tree growth for a tree species called A. Borisii-regis in the Mediterranean. They found that rainfall was the key driving factor for tree growth during the study period. Ademe et al. [2] demonstrated that the change in the water flow of the Birr River in Ethiopia was not only influenced by the change in rainfall but was also due to changes in land cover and land use, as well as human interventions, such as upstream water abstraction. In another study by Chaluka et al. [3], it was found that changes in rainfall influenced the alterations in streamflow patterns. Bellabas et al. [8] used a climate elasticity model and a hydrologic model to examine the effects of anthropogenic activities and changes in climate on streamflow. The results revealed that anthropogenic reasons were the dominant causes for the alterations in streamflow. In contrast to the above results, several others, such as Hannaford [12] and Wang et al. [13], found that the variations in rainfall significantly influenced streamflow patterns. Moreover, studies such as those by Azari et al. [14], Dey and Mishra [15], and Xu et al. [16] found that climate change had impacts on streamflow changes to varying degrees. Most of the trend analysis studies [2,3,17] used the Mann–Kendall test and Sen's slope estimator to study rainfall and streamflow trends. Pettitt's test was used for the detection of changing points in a hydrometeorological time series [18–21]. Other trend analysis methods, such as Spearman's rho and the linear regression test, were used by Fentaw et al. [9] and Coloiero [22]. However, some of these should be performed under certain assumptions, for instance, when the data is normally distributed and there are specific criteria on the length of the data series [22]. The indicators of hydrologic alteration (IHA) are commonly used to identify the hydrological impacts of human activities and to provide recommendations for environmental flow management [23–25].

Sri Lanka is an agrarian country that is highly dependent on rainfed and irrigation water. According to the Annual Report of the Central Bank of Sri Lanka, in 2021, the agriculture sector contributed 6.9% of the gross domestic product. Nearly 27.3% of Sri Lankans' engage in the agricultural sector as their livelihood. Sri Lanka experiences two major monsoon periods, which are the northeast monsoon (NEM; December to February) and the southwest monsoon (SWM; May to September). The two inter-monsoon periods are the first inter-monsoon (FIM; March to April) and the second inter-monsoon (SIM; October to November) [26].

Several studies, including Abeysingha [27], Perera et al. [28], Alahacoon and Edirisinghe [29], and Ruwangika et al. [30], studied rainfall and streamflow trends in Sri Lanka. These studies identified an increasing rainfall trend over the country that was most prominent in the eastern, southeastern, north, and north–central areas. Jayasekara and Abeysingha [17] found that there was a significant association between streamflow and rainfall variations for 70% of gauging stations in the Kelani River Basin. Chathuranika et al. [26] found that the climate and streamflow conditions of the Nilwala River Basin are expected to change in the future relative to the current conditions. Even though rainfall and streamflow trends studies were carried out in Sri Lanka, a handful of them focused on extreme rainfall indices, while none of the document studies used IHA parameters to assess the shifts in hydrologic regimes. Rainfall and streamflow trends and variabilities and their existing linkages have not been assessed for the Nilwala River Basin (NRB), which is one of the major river basins in the southern part of the island. Therefore, this study aimed to analyze long-term rainfall and streamflow trends, detect change points, and identify hydrological variables and their linkage over the NRB. The findings of this study will be helpful for both public and private sectors that are involved in water resource planning and development, disaster management, agricultural development, etc.

2. Materials and Methods

2.1. Study Area

The Nilwala River Basin (NRB) is in the southern part of the country between latitudes 5°55′ N and 6°13′ N and between longitudes 80°25′ E and 80°38′ E [4]. The river originates from Panilkanda in Deniyaya at an altitude of 988 m above the MSL (mean sea level), flows about 72 km through agricultural, urban, and other land uses, and finally drains into the Indian Ocean in Matara [31]. The total basin area is about 1010 km^2. The annual discharge of the river is more than 800 million cubic meters (MCM). The mean annual precipitation of the upper part of the NRB is about 3000 mm, while in the lower part, it is about 1900 mm [26]. Figure 1 demonstrates rainfall and hydrological stations in the NRB.

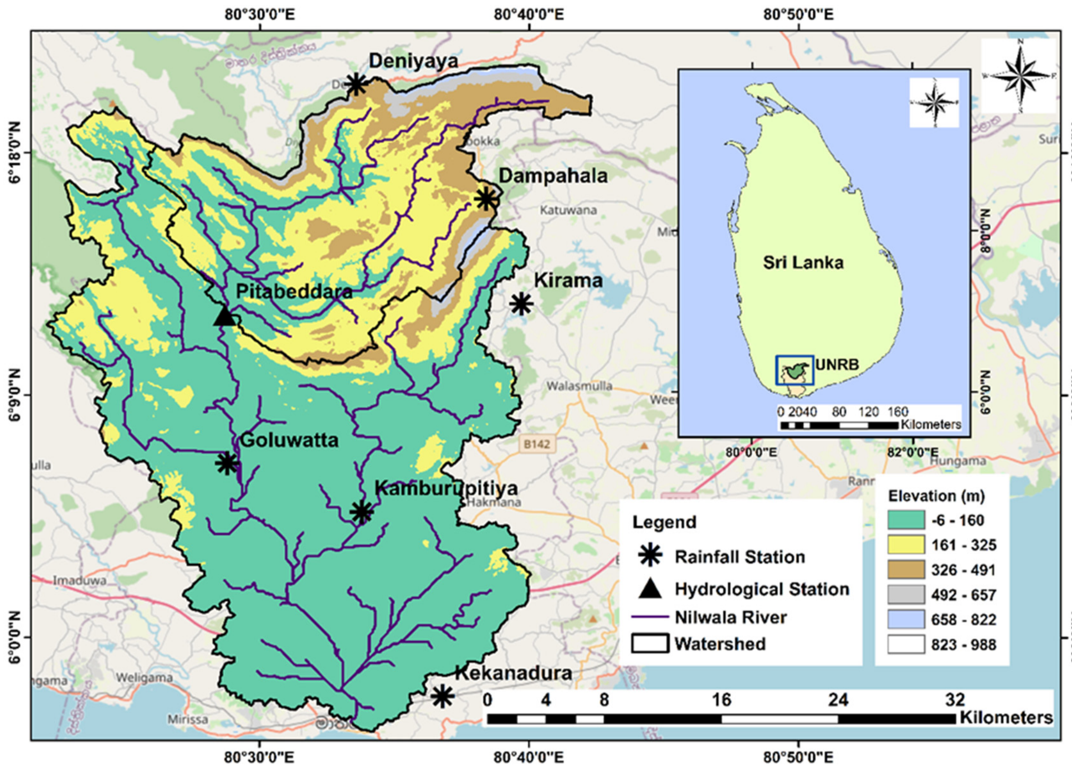

Figure 1. Location map of Nilwala River Basin with rainfall and hydrological stations.

2.2. Rainfall and Streamflow Data

2.2.1. Observed Data

Daily observed rainfall data from 1991–2014 (24 years) for six stations, namely, Dampahala, Kamburupitiya, Kekenadura, Kirama, Goluwawatta, and Deniyaya, were collected from the Department of Meteorology of Sri Lanka. Daily observed discharge data for the Pitabeddara hydrological station was collected from the Department of Irrigation of Sri Lanka for the same period.

2.2.2. Gridded Data

Missing rainfall data were filled using two versions of the Asian Precipitation-Highly Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE) products, namely, V1101_MA and V1901_MA, with the same resolutions of 0.25° × 0.25°. APHRODITE products are available in three main geographical domains: Monsoon Asia (MA), Middle East (ME), and Russia (RU) (http://aphrodite.st.hirosaki-u.ac.jp/, accessed on 2 August 2022) [26]. The high temporal and spatial resolution in APHRODITE when compared with other gridded-based products and well-developed quality control methods influenced researchers to use this gridded product. Yatagai et al. [32], Yatagai et al. [33], and many other studies used APHRODITE data products for climatological studies, to validate satellite data, and to downscale low-resolution model data. Table 1 provides the general information of the stations used in the present study.

Table 1. General information of the stations used.

Station	Latitude (N)	Longitude (E)	Elevation (m.a.s.l)	Period	Missing %
Meteorological stations					
Dampahala	6.27	80.64	176		25.03
Kamburupitiya	6.08	80.56	244	1991–2014	5.91
Kekenadura	5.97	80.57	49		3.49
Kirama	6.22	80.67	122		3.79
Goluwawatta	6.10	80.48	16		17.10
Deniyaya	6.33	80.55	399		24.66
Hydrological station					
Pitabaddara	6.20	80.48	27	1991–2014	0.205

2.3. Methodology

Initially, the data quality and consistency were checked, and missing rainfall data were filled in using the APHRODITE precipitation data. Both hydrological and meteorological data were categorized into monthly, seasonal, and annual timescales. Mann–Kendall, modified Mann–Kendall, Sen's slope estimator, and Pettitt's tests were performed to identify the trends in the rainfall data and streamflow data to compute their magnitudes and to detect change points in the time series data using XLSTAT software (available at https://www.xlstat.com/en/, accessed on 5 August 2022) [34]. In addition, 5 extreme rainfall indices were calculated using the RClimdex software (available at https://www.climdex.org/, accessed on 9 August 2022) [35] and computed trends and magnitudes were found using MK and Sen's slope tests. The correlation between rainfall and streamflow was analyzed using Pearson's correlation coefficient. Thereafter, indicators of hydrological alteration (IHA) software was used to analyze the variations of the 16 selected hydrological parameters. Figure 2 below demonstrates the overall methodology of the study.

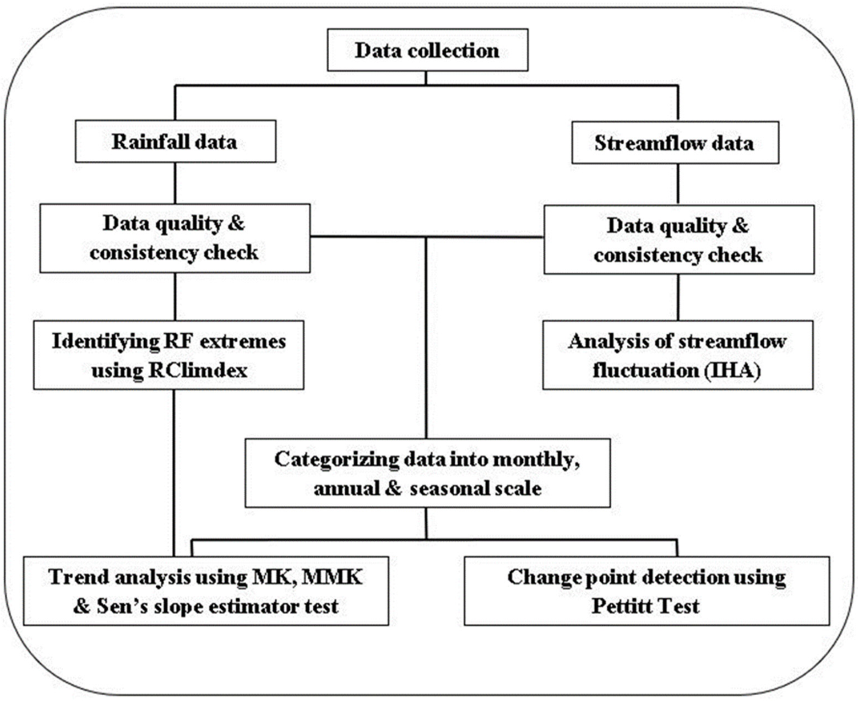

Figure 2. Overall methodology.

2.4. Trend Analysis Methods

2.4.1. Mann–Kendall Test

The non-parametric Mann-Kendall test [36,37] was used to identify the rainfall trends. The Mann–Kendall test static S was calculated using the following Equations (1) and (2):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i), \tag{1}$$

$$sgn(x_j - x_i) = \begin{cases} +1 & if\ x_j > x_i \\ 0 & if\ x_j = x_i \\ -1 & if\ x_j < x_i \end{cases} \tag{2}$$

where x_j and x_i are the data values at times *j* and *i* (*j* > *i*) and n is the length of the data series.

The Mann–Kendall Z statics and the variance *Var(S)* were calculated using the following Equations (3) and (4):

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(S)}} \\ 0 \\ \frac{s+1}{\sqrt{Var(S)}} \end{cases}, \qquad if \begin{bmatrix} S > 0 \\ S = 0 \\ S < 0 \end{bmatrix} \tag{3}$$

The Mann–Kendall test accepts the null hypothesis if $-Z \leq Zcr \leq Z$ is the critical value of the normalized statics *Z* at a 5% confidence level. The negative and positive values of *Z* and *S* statistics indicate decreasing and increasing tendencies, respectively.

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5)] \tag{4}$$

2.4.2. Modified Mann–Kendall Test

Importantly, the influence of the accuracy of values in time series data on each other is highly affected by the serial correlation. The serial correlation is present in hydrologic data sets, such as streamflow and water levels [38–41]. The presence of a positive serial correlation will increase the ability to show trends from a certain level other than the actual status, and sometimes it shows trends that have no significant trends in the actual scenario [42]. Therefore, a serial correlation check should be conducted before applying the MK test. If a serial correlation is present, the modified Mann–Kendall test proposed by Hamed and Rao [42] should be applied to the time series data to eliminate the effects of serial correlation. Trend analysis of the hydrological data was checked using the modified Mann–Kendall (MMK) test and the modified variance can be calculated using the following Equations (5) and (6):

$$Var(S)^* = Var(S)\frac{n}{n^{*\prime}} \tag{5}$$

where *Var(S)** is the modified variance and the correction factor $n/n^{*\prime}$ is given by the following Equation (6):

$$\frac{n}{n^{*\prime}} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{j=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_{k'}^{R} \tag{6}$$

where n is the actual number of observations, n^* is the effective number of observations to count for the auto-correlation data, and $r_{k'}^{R}$ is the lag k autocorrelation coefficient of the rank of data.

2.5. Sen's Slope Estimator

Sen's slope estimator [43] is also a non-parametric test that is widely used to compute the magnitude of trend series. The slope of the data series is computed using the following Equations (7) and (8):

$$T_i = \frac{X_j - X_k}{j - k} \quad Fori = 1,\ 2,\ 3 \ldots N \tag{7}$$

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+1}}{2}\right) & N\ is\ even \end{cases} \tag{8}$$

where x_j and x_i are data values at the time j and k ($j < k$). N is the number of data pairs (x_j, x_k), $1 \leq j < k \leq n$. β defines Sen's slope value. Positive β values signify an increasing trend and negative β values signify a decreasing trend

2.6. Change Point Detection

The nonparametric Pettitt's test developed by Pettitt [44] was used to identify abrupt changes in time rainfall data within the study area. The method was derived using the Mann–Whitney statistic $U_{t,\ n}$ and two test samples from the same population, namely, $x_1, \ldots, x_t$ and $x_{t+1}, \ldots, x_n$. The test statistic $U_{t,\ n}$ can be obtained using the following Equations (9) and (10):

$$U_{t,\ n} = U_{t-1,\ n} + \sum_{J=1}^{n} sgn\left(x_t - x_j\right) \tag{9}$$

where $t = 2, 3, \ldots, n$; n is the length of the time series; and

$$\begin{aligned} \text{If } \left(x_t - x_j\right) > 0,\ sgn\left(x_t - x_j\right) = 1 \\ \text{If } \left(x_t - x_j\right) = 0,\ sgn(x_t - x) = 0 \\ \text{If } \left(x_t - x_j\right) < 0,\ sgn\left(x_t - x_j\right) < -1 \end{aligned} \tag{10}$$

The test statistic quantifies the number of times when the first sample exceeds the second sample. The null hypothesis test indicates there are no changes in the data series, while the alternative hypothesis indicates the existence of changing points in the data series. The commonly used 5% significant level was used for the analysis. The test statistic K_n and the associate probability P used in the test can be obtained using the following Equations (11) and (12), respectively:

$$K_n = max_{1 \leq t \leq n} |U_{t,\ n}| \tag{11}$$

$$P \cong 2exp\left\{ \frac{-6(K_n)^2}{(n^3 + n^2)} \right\} \tag{12}$$

2.7. Indicators of Hydrological Alteration (IHA)

IHA software was developed by the US Nature Conservancy to measure the extent of hydrological changes due to climatic and human influences [21]. This tool has the ability to calculate 33 IHA parameters under five categories: magnitudes of monthly water conditions, magnitude and duration of annual extreme water conditions, the timing of annual extreme water conditions, frequency and duration of high/low pulses, and rate/frequency of water condition changes. A 5% significance level p-value was used to evaluate and compare the parameters' consistency.

2.8. RClimdex

RClimdex software was developed and maintained by Xuebin Zhang and Feng Yang at the Climate Research Branch of the Meteorological Service of Canada and designed to obtain 27 climate extreme indices that are recommended by the Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) [4]. This study used five selected extreme precipitation indices: consecutive dry days (CDD), consecutive wet days (CWD), annual total wet day precipitation (PRCPTOT), number of days above 25 mm (R25), and maximum 5-day precipitation amount (Rx5) [45].

3. Results and Discussion

3.1. Correlation between Observed and APHRODITE Data

Since rainfall was missing from some of the rainfall stations, gridded precipitation data were used to fill them. To check the reliability, the correlation coefficient was calculated between the observed data and APHRODITE products V1901 (from January 2004 to March 2015) and V1101 (from February 1991 to September 1991). The longest and continuous data periods that were common for both the observed and APHRODITE data were selected on this basis. The results of the correlation are shown in Table 2 below. Most of the stations showed a moderate-to-very-strong relationship in the correlation analysis. Hence, we could justify the use of APHRODITE data for our study. The types of correlations were classified as per the rule of thumb for interpreting the correlation coefficient. The classification for the Pearson correlation coefficient was as follows: a positive very strong correlation was 0.8–1.0, a positive strong correlation was 0.6–0.8, a positive strong moderate correlation was 0.4–0.6, a positive moderate correlation was 0.2–0.4, and a positive weak or insignificant correlation was 0–0.2 [3].

Table 2. Results of correlation check—observed data vs. APHRODITE data.

Station	V1901 (January 2004–March 2005)		V1101 (February 1991–September 1991)	
	Correlation	Correlation Type	Correlation	Correlation Type
Dampahala	0.47	Positive moderate	0.12	Positive weak
Kamburupitiya	0.79	Positive very strong	0.69	Positive strong
Kekenadura	0.85	Positive very strong	0.61	Positive strong
Kirama	0.28	Positive weak	0.02	Positive weak
Goluwawatta	0.77	Positive very strong	0.38	Positive moderate
Deniyaya	0.45	Positive moderate	0.75	Positive very strong

3.2. Trend Analysis of the Rainfall

Trend analysis was carried out for the monthly, seasonal, and annual scales using Mann–Kendall and Sen's slope tests. The significant trends are denoted in bold font in Table 3. Dampahala station showed significant increasing trends in March, September, November, and December, with magnitudes of 12.2 mm/yr, 8.96 mm/yr, 14.26 mm/yr, and 11.65 mm/yr, respectively. Kamburupitiya showed significant decreasing trends of 3.97 mm/yr in July. Kirama demonstrated significant decreasing trends in April, June, and July, with magnitudes of 7.23 mm/yr, 4.63 mm/yr, and 4.61 mm/yr, respectively. Deniyaya also revealed a significant 13.83 mm/yr decreasing trend in May, while Kekenadura and Goluwatta did not show any significant trends at the monthly scale. In general, most of the stations showed decreasing patterns at the monthly scale. Interestingly, Deniyaya showed only decreasing trends and Dampahala showed only increasing trends. Dampahala showed a significant increasing trend of 73.85 mm/yr, while Deniyaya showed a significant decreasing trend of 70.3 mm/yr at the annual scale. At the seasonal scale, Dampahala station revealed significant increasing trends during the NEM and FIM, with magnitudes of 23.43 mm/yr and 17.42 mm/yr, respectively. During the SWM, Kamburupitiya, Kirama, and Deniyaya showed significant 16.83 mm/yr, 11.68 mm/yr, and 33.19 mm/yr decreasing trends, respectively. During the SIM period, only the Deniyaya station revealed a significant decreasing trend, with a magnitude of 13.89 mm/yr. The highest magnitudes of increasing trends at the monthly (November) and annual scales and for the NEM and FIM were identified in the Dampahala station. Deniyaya exhibited the highest significant decreasing trends at the monthly (May) and annual scales and for the SWM and SIM. Other stations, except for Dampahala, experienced decreasing trends at the monthly and annual scales and for the SWM and FIM.

Table 3. Trend analysis results for the rainfall data.

Timescale	Dampahala			Kamburupitiya			Kekenadura			Kirama			Goluwatta			Deniyaya		
	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**
January	0.188	2.88	NSIT	0.941	0.11	NSIT	0.747	0.53	NSIT	0.551	1.39	NSIT	0.941	0.37	NSIT	0.637	−1.33	NSDT
February	0.108	7.08	NSIT	0.823	−0.40	NSDT	0.747	0.89	NSIT	0.823	−0.19	NSDT	0.980	0.49	NSIT	0.063	−9.49	NSDT
March	**0.005**	**12.20**	**SIT**	0.248	1.72	NSIT	0.136	1.57	NSIT	0.205	2.55	NSIT	0.941	0.50	NSIT	0.333	−2.78	NSDT
April	0.132	8.46	NSIT	0.248	−3.93	NSDT	0.209	−2.18	NSDT	**0.039**	**−7.23**	**SDT**	0.713	−1.25	NSDT	0.188	−10.12	NSDT
May	0.338	4.86	NSIT	0.268	−3.57	NSDT	0.447	−3.08	NSDT	0.980	−0.20	NSDT	0.160	−4.61	NSDT	**0.039**	**−13.83**	**SDT**
June	0.677	1.59	NSIT	0.063	−4.45	NSDT	0.788	0.91	NSIT	**0.050**	**−4.63**	**SDT**	0.864	−0.44	NSDT	0.118	−8.26	NSDT
July	0.677	1.24	NSIT	**0.044**	**−3.97**	**SDT**	0.175	−2.16	NSDT	**0.002**	**−4.61**	**SDT**	0.192	−3.38	NSDT	0.078	−3.01	NSDT
August	0.390	3.77	NSIT	0.750	0.69	NSIT	0.244	2.73	NSIT	0.785	−0.42	NSDT	0.540	1.51	NSIT	0.535	−2.22	NSDT
September	**0.020**	**8.96**	**SIT**	0.192	−4.33	NSDT	0.573	−1.31	NSDT	0.338	−2.02	NSDT	0.192	−5.17	NSDT	0.823	−0.72	NSDT
October	0.364	2.62	NSIT	0.903	0.69	NSIT	0.602	2.44	NSIT	0.903	0.66	NSIT	0.607	−2.09	NSDT	0.078	−7.56	NSDT
November	**0.017**	**14.26**	**SIT**	0.826	−0.62	NSDT	0.677	−2.28	NSDT	0.338	3.55	NSIT	0.418	−2.58	NSDT	0.188	−4.32	NSDT
December	**0.003**	**11.65**	**SIT**	0.120	5.60	NSIT	0.108	4.66	NSIT	0.338	3.49	NSIT	0.573	1.50	NSIT	0.980	−0.06	NSDT
Annual	**0.034**	**73.85**	**SIT**	0.314	−13.94	NSDT	0.713	5.03	NSIT	0.677	−8.62	NSDT	0.228	−17.06	NSDT	**0.002**	**−70.30**	**SDT**
NEM	**0.013**	**23.43**	**SIT**	0.268	6.49	NSIT	0.145	4.05	NSIT	0.750	4.93	NSIT	0.750	−1.81	NSDT	0.160	−15.75	NSDT
FIM	**0.015**	**17.42**	**SIT**	0.477	−2.96	NSDT	0.826	−0.74	NSDT	0.314	−6.48	NSDT	0.747	−2.10	NSDT	0.056	−17.21	NSDT
SWM	0.268	17.64	NSIT	**0.007**	**−16.83**	**SDT**	0.338	−8.45	NSDT	**0.050**	**−11.68**	**SDT**	0.088	−14.58	NSDT	**0.003**	**−33.19**	**SDT**
SIM	0.063	16.44	NSIT	0.941	−0.40	NSDT	0.637	3.22	NSIT	0.477	3.47	NSIT	0.447	−6.36	NSDT	**0.031**	**−13.98**	**SDT**

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, SIT refers to a significant increasing trend, SDT refers to a significant decreasing trend.

3.3. Trend Analysis of the Streamflow

Trend analysis of the streamflow at the Pitabeddara hydrologic station was computed for the monthly, seasonal, and annual scales. According to the results in Table 4, only one significant trend was observed, which was in December with a magnitude of 0.59 m^3s^{-1}/yr. During the other months, non-significant increasing and decreasing trends were observed. Significant trends were not observed on the annual or seasonal scale. However, non-significant increasing trends were observed for the annual scale and the NEM and FIM. Non-significant decreasing trends during the SWM and SIM were seen.

Table 4. Trend analysis results for the streamflow data.

Timescale	Kendall's Tau	*p*-Value	Sen's Slope	Trend Type
January	0.152	0.298	0.17	NSIT
February	0.123	0.399	0.13	NSIT
March	0.217	0.137	0.25	NSIT
April	0.123	0.399	0.15	NSIT
May	−0.058	0.691	−0.15	NSDT
June	−0.080	0.567	−0.15	NSDT
July	−0.130	0.372	−0.18	NSDT
August	−0.051	0.728	−0.02	NSDT
September	−0.014	0.921	−0.10	NSDT
October	−0.196	0.067	−0.30	NSDT
November	0.101	0.487	0.26	NSIT
December	0.319	**0.029**	**0.59**	**SIT**
Annual	0.094	0.519	0.10	NSIT
NEM	0.275	0.059	0.31	NSIT
FIM	0.203	0.165	0.20	NSIT
SWM	−0.159	0.275	−0.12	NSDT
SIM	−0.036	0.804	−0.03	NSDT

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, SIT refers to a significant increasing trend, SDT refers to a significant decreasing trend.

3.4. Trend Analysis of the Extreme Rainfall Indices

Five selected extreme rainfall indices, namely, consecutive dry days (CDD), consecutive wet days (CWD), annual total wet day precipitation (PRCPTOT), number of days above 25 mm (R25), and maximum 5-day precipitation amount (Rx5), were computed using the RClimdex software. According to the results shown in Table 5, Dampahala station revealed significant increasing trends in PRCPTOT and R25, with magnitudes of 74.55 mm/yr and 1.64 days/yr. In Deniyaya, significant decreasing trends in PRCPTOT and R25 were observed, with magnitudes of 71.75 mm/yr and 1.33 days/yr. Kamburupitiya showed a 0.7 days/yr significant decreasing trend for CWD. No significant trends were observed for the Kekenadura, Kirama, and Goluwatta stations for CDD, CWD, PRCPTOT, and R25.

Table 5. Trend analysis results for the extreme rainfall indices.

Station	Extremes	Kendall's Tau	*p*-Value	Sen's Slope	Trend Type
Dampahala	CDD	−0.115	0.440	−0.14	NSDT
	CWD	−0.268	0.070	−0.38	NSDT
	PRCPTOT	0.312	**0.034**	**74.55**	**SIT**
	R25	0.396	**0.007**	**1.64**	**SIT**
Kamburupitiya	CDD	0.129	0.384	0.20	NSIT
	CWD	−0.462	**0.002**	**−0.70**	**SDT**
	PRCPTOT	−0.145	0.338	−14.53	NSDT
	R25	0.106	0.471	0.23	NSIT

Table 5. *Cont.*

Station	Extremes	Kendall's Tau	*p*-Value	Sen's Slope	Trend Type
Kekenadura	CDD	−0.172	0.243	−0.31	NSDT
	CWD	−0.061	0.688	0.00	No trend
	PRCPTOT	0.065	0.677	5.60	NSIT
	R25	0.030	0.842	0.00	No trend
Kirama	CDD	0.128	0.384	0.57	NSIT
	CWD	−0.282	0.065	−0.12	NSDT
	PRCPTOT	−0.058	0.713	−8.45	NSDT
	R25	−0.022	0.881	0.00	No trend
Goluwatta	CDD	−0.069	0.637	−0.10	NSDT
	CWD	−0.134	0.369	−0.15	NSDT
	PRCPTOT	−0.174	0.248	−18.10	NSDT
	R25	−0.274	0.065	−0.60	NSDT
Deniyaya	CDD	0.101	0.500	0.09	NSIT
	CWD	−0.044	0.765	−0.04	NSDT
	PRCPTOT	−0.454	**0.002**	**−71.75**	**SDT**
	R25	−0.442	**0.003**	**−1.33**	**SDT**

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, SIT refers to a significant increasing trend, SDT refers to a significant decreasing trend.

Tables 6 and 7 present the trend results of Rx5. According to the trend results of Rx5, significant increasing trends in March, September, and December were found for the Dampahala station, with values of 5.76 mm/yr, 4.92 mm/yr, and 5.25 mm/yr. Kamburupitiya revealed a 3.38 mm/yr significant increasing trend in December, while in the annual scale analysis, Kamburupitya revealed a significant decreasing trend, with a magnitude of 3.63 mm/yr. Kirama and Goluwatta stations also revealed decreasing trends in July and May, with magnitudes of 3.34 mm/yr and 4.0 mm/yr, respectively. Deniyaya revealed a comparatively high number of significant decreasing trend events in February, April, May, June, and November, and at the annual scale, with magnitudes of 4.24 mm/yr, 3.13 mm/yr, 5.24 mm/yr, 4,88 mm/yr, 4.81 mm/yr, and 6.45 mm/yr respectively. Generally, Rx5 showed more significant decreasing trends in both monthly and annual scales at most stations.

Table 6. Trend analysis results for the extreme rainfall indices (Rx5).

Timescale	Dampahala			Kamburupitiya			Kekenadura		
	p-Value	Sen's Slope	Trend Type	*p*-Value	Sen's Slope	Trend Type	*p*-Value	Sen's Slope	Trend Type
January	0.082	2.64	NSIT	0.642	0.56	NSIT	0.607	0.54	NSIT
February	0.314	2.48	NSIT	0.903	0.12	NSIT	0.215	1.49	NSIT
March	**0.002**	**5.76**	**SIT**	0.710	0.39	NSIT	0.228	1.10	NSIT
April	0.132	4.51	NSIT	0.096	−2.56	NSDT	0.508	−0.81	NDIT
May	0.096	3.05	NSIT	0.268	−1.99	NSDT	0.145	−2.45	NDIT
June	0.338	1.88	NSIT	0.143	−2.58	NSDT	0.864	0.27	NSIT
July	0.607	0.70	NSIT	0.447	−0.44	NSDT	0.079	−1.46	NDIT
August	0.442	1.38	NSIT	0.607	0.75	NSIT	0.124	1.56	NSIT
September	**0.008**	**4.92**	**SIT**	0.447	−1.43	NSDT	0.359	−1.78	NDIT
October	0.070	2.56	NSIT	0.710	−0.35	NSDT	0.785	−0.22	NDIT
November	0.078	3.87	NSIT	0.573	−0.59	NSDT	0.921	0.07	NSIT
December	**0.007**	**5.25**	**SIT**	**0.030**	**3.38**	**SIT**	0.192	2.16	NSIT
Annual	0.244	4.32	NSIT	**0.030**	**−3.63**	**SDT**	0.228	−1.11	NDIT

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, SIT refers to a significant increasing trend, SDT refers to a significant decreasing trend.

Table 7. Trend analysis results for the extreme rainfall indices (Rx5).

Timescale	Kirama			Goluwatta			Deniyaya		
	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**	***p*-Value**	**Sen's Slope**	**Trend Type**
January	0.385	1.35	NSIT	0.788	−0.25	NSDT	0.508	−1.10	NDIT
February	0.901	0.12	NSIT	0.750	−0.98	NSDT	**0.027**	**−4.24**	**SDT**
March	0.413	0.80	NSIT	0.980	−0.01	NSDT	0.070	−3.19	NDIT
April	0.160	−2.68	NSDT	0.980	0.09	NSIT	**0.050**	**−3.13**	**SDT**
May	0.901	0.27	NSIT	**0.014**	**−4.00**	**SDT**	**0.024**	**−5.24**	**SDT**
June	0.130	−1.62	NSDT	0.447	−1.65	NSDT	**0.050**	**−4.88**	**SDT**
July	**0.003**	**−3.34**	**SDT**	0.607	−0.95	NSDT	0.172	−1.08	NDIT
August	0.766	0.31	NSIT	0.941	−0.05	NSDT	0.087	−2.05	NDIT
September	0.290	−1.57	NSDT	0.107	−3.35	NSDT	0.286	−1.59	NDIT
October	0.677	0.78	NSIT	0.175	−2.68	NSDT	0.941	0.11	NSIT
November	0.862	0.10	NSIT	0.314	−2.32	NSDT	**0.039**	**−4.81**	**SDT**
December	0.160	1.84	NSIT	0.673	0.66	NSIT	0.862	0.62	NSIT
Annual	0.209	−1.41	NSDT	0.070	−5.52	NSDT	**0.014**	**−6.45**	**SDT**

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, SIT refers to a significant increasing trend, SDT refers to a significant decreasing trend.

3.5. Change Point Detection in the Rainfall Data

Pettitt's test results, which showed statistically significant changes at the annual and seasonal scales, are shown in Figure 3. Most stations did not show significant increasing or decreasing changes at both scales. The annual scale results of the Pettit's test at Dampahala revealed a significant increasing shift in the year 1998 and Deniyaya revealed a significant decreasing shift in the year 2000. However, the Dampahala station showed significant increasing shifts in 1998 during the NEM, FIM, and SIM. Moreover, Kamburupitiya and Deniyaya showed significant decreasing changes in 1998 and 1999, respectively.

Table 8 shows a few significant changes in the monthly Pettitt's test results for the Dampahala, Kamburupitiya, Kirama, and Deniyaya rainfall stations. The Dampahala station revealed significant increasing changes during March, September, and December in 1999, 1999, and 1997, respectively. The Kamburupitiya station revealed a significant decreasing shift in July 1998. Moreover, the Kirama station showed significant decreasing shifts in June 2000 and July 2005, and the Deniyaya station showed a significant decreasing change in October 1997.

Table 8. Pettitt's test results of monthly rainfall data.

Station	Month	*p*-Value	Change Point	Shift
Dampahala	March	0.014	1999	Upward
	September	0.040	1999	Upward
	December	0.020	1997	Upward
Kamburupitiya	July	0.031	1998	Downward
Kirama	June	0.013	2000	Downward
	July	0.007	2005	Downward
Deniyaya	October	0.034	1997	Downward

3.6. Linkage between Rainfall and Streamflow

Pearson's correlation was used to analyze the relationship between rainfall and streamflow during 1991–2014 at the monthly, annual, and seasonal timescales. Considering the contribution of rainfall to the Pitabeddara streamflow station, only the Dampahala, Kirama, and Deniyaya stations were chosen to find the existing linkages between rainfall and streamflow. The results of the correlation analysis are given in Table 9.

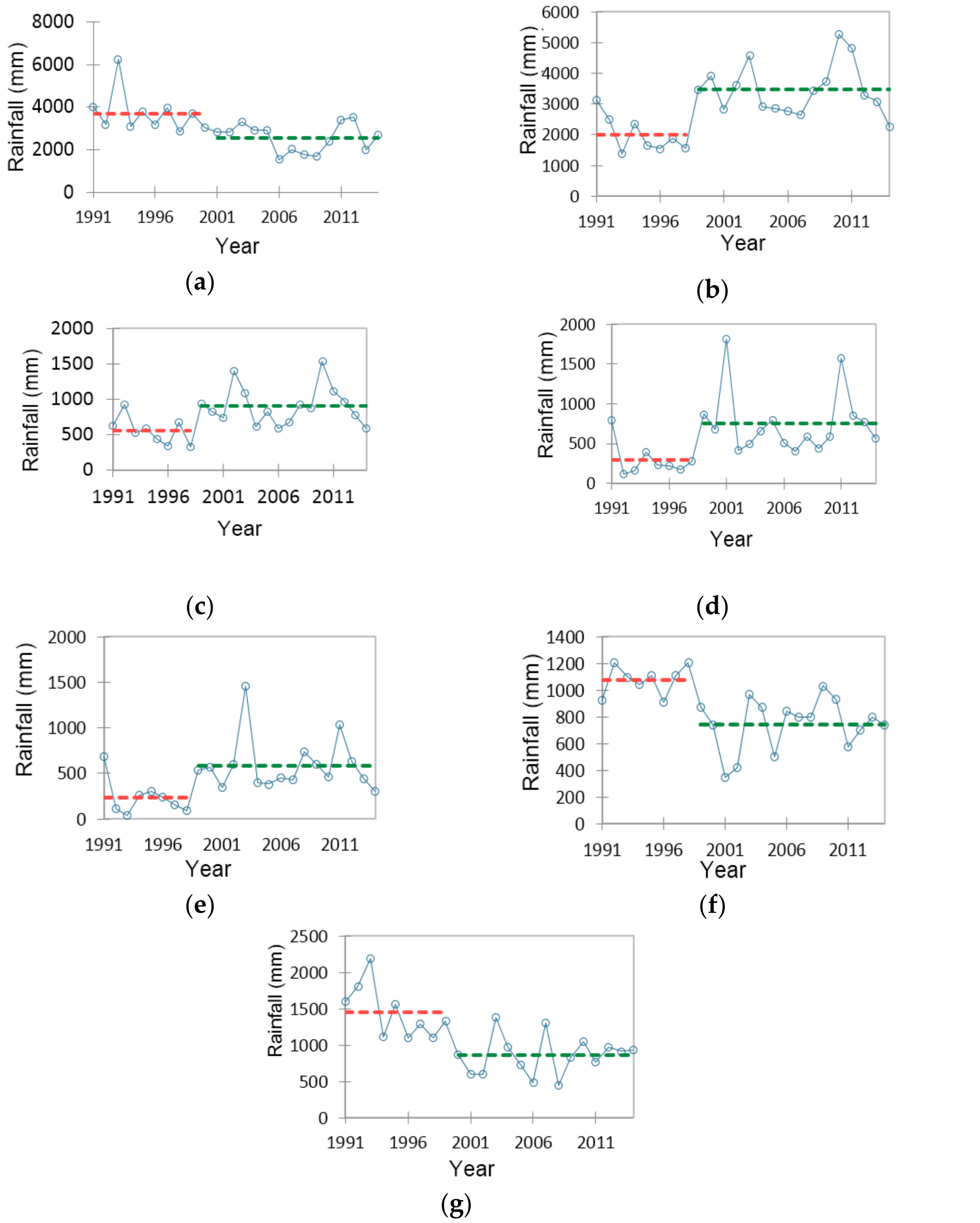

Figure 3. Pettitt's test results of the annual and seasonal rainfall data: (**a**) Deniyaya annual, (**b**) Dampahala annual, (**c**) Dampahala SIM, (**d**) Dampahala NEM, (**e**) Dampahala FIM, (**f**) Kamburupitiya SWM, and (**g**) Deniyaya SWM.

The Pearson correlation results indicated that February, March, May, and September showed positive very strong correlations, while January, June, November, and December showed positive strong correlations between rainfall and streamflow. Moreover, at the monthly scale, April, July, and October showed positive strong moderate correlations between rainfall and streamflow, while August had a positive moderate correlation. The annual scale results showed a positive strong moderate correlation between rainfall and streamflow. At the seasonal scales, a positive very strong correlation was observed for the NEM, and the FIM showed a positive strong moderate correlation. Both the SWM and SIM periods showed positive strong correlations between the rainfall and streamflow data.

Table 9. Pearson correlation results.

Timescale	Correlation	Linkage between Rainfall and Streamflow
January	0.79	*PSC*
February	0.85	*PSVC*
March	0.85	*PSVC*
April	0.40	*PSMC*
May	0.85	*PSVC*
June	0.72	*PSC*
July	0.46	*PSMC*
August	0.33	*PMC*
September	0.80	*PSVC*
October	0.56	*PSMC*
November	0.61	*PSC*
December	0.71	*PSC*
Annual	0.55	*PSMC*
NEM	0.81	*PSVC*
FIM	0.58	*PSMC*
SWM	0.62	*PSC*
SIM	0.67	*PSC*

PSC—positive strong correlation; *PVSC*—positive very strong correlation; *PSMC*—positive strong moderate correlation; *PMC*—positive moderate correlation.

3.7. Indicators of Hydrological Alteration (IHA)

According to the literature based on the NRB, no major obstruction or dam was built. However, we decided to investigate the changes in the flow regime before and after 2003. This year was selected purely arbitrarily. Two-period parametric analysis was used in this IHA method. The pre-impact period was chosen from 1991–2003 and the post-impact period was selected from 2004–2014. This section discusses 16 selected hydrological parameters out of the 33 that fall under the main IHA parameter groups of magnitude and duration of annual extreme water conditions, timing of annual extreme water conditions, and frequency and duration of high and low pulses. According to the IHA analysis, the mean annual flow during the post-impact period increased slightly from 15.87 m^3s^{-1} to 16.23 m^3s^{-1}. Table 10 given below demonstrates the statistics for the pre-impact and post-impact periods for the selected IHA parameters.

Table 10. IHA results.

IHA Parameters	Means			Coefficient of Variation		
	Pre-Impact	Post-Impact	Deviation Factor (%)	Pre-Impact	Post-Impact	Deviation of C.V (%)
Magnitude and Duration (IHA Group 2)						
1-day minimum	2.375	2.322	−2.223	0.4769	0.3378	−29.17
3-day minimum	2.466	2.424	−1.71	0.4594	0.3298	−28.22
7-day minimum	2.766	2.723	−1.564	0.449	0.3073	−31.56
30-day minimum	4.171	4.224	1.266	0.4171	0.3226	−22.67
90-day minimum	6.564	7.762	18.26	0.3865	0.2785	−27.96
1-day maximum	189.2	136.3	−27.94	0.5865	0.3681	−37.24
3-day maximum	129.9	89.85	−30.82	0.7325	0.4233	−42.21
7-day maximum	82.79	63.03	−23.87	0.5919	0.334	−43.56
30-day maximum	43.27	40.66	−6.036	0.3191	0.3589	12.48
90-day maximum	28.46	27	−5.138	0.2447	0.2198	−10.2
No. of zero days	0	0	-	0	0	-
Baseflow index	0.1722	0.1737	0.8578	0.401	0.3362	−16.14
Timing (IHA Group 3)						
Date of each annual 1-day minimum	113	199.5	47.24	0.1857	0.2228	19.96

Table 10. *Cont.*

IHA Parameters	Means			Coefficient of Variation		
	Pre-Impact	Post-Impact	Deviation Factor (%)	Pre-Impact	Post-Impact	Deviation of C.V (%)
Date of each annual 1-day maximum	211.5	261.5	27.28	0.2693	0.2606	−3.227
Frequency (IHA Group 4)						
No. of low pulses in each year	14.54	13.36	−8.081	0.2731	0.4628	69.54
No. of high pulses in each year	12.54	13.73	9.481	0.4253	0.3092	−27.29

Although notable changes were not observed for minimum flows in IHA group 2, maximum flows decreased significantly during the post-impact period. For instance, the 1-day maximum, 3-day maximum, and 7-day maximum flows decreased by 27.94%, 30.82%, and 23.87%, respectively. The only notable change in minimum flow was the 90-day minimum flow with an increase of 18.26%.

Results of the IHA group 3 parameters in Table 9 showed that the annual 1-day minimum flow was recorded on the 113th Julian date in the calendar for the pre-impact period and the 119th and 120th days for the post-impact period; this showed that the date shifted a little bit forward in the post-impact period. Julian's date of each annual 1-day maximum for the pre-impact was recorded during the 211th and 212th days, and for the post-impact period, it was recorded during the 261st and 262nd days.

According to the results in Table 10 under the IHA group 3 category, 14.56 low pulses were found in the pre-impact period, which decreased to 13.36 per year during the post-impact period. The coefficient of variation for the low pulses was increased by 69.54% from the pre-impact to post-impact period. The number of high pulses for each year in the pre-impact period was found to be 12.54 per year, which increased in the post-impact period up to 13.73 per year. The deviation of the coefficient of variation also decreased by 27.29% from the pre-impact to post-impact period.

3.8. Discussion

According to the results found in the present study, most of the stations showed decreasing rainfall trend patterns at the monthly scale. Generally, the annual scale and the FIM and SWM exhibited decreasing rainfall trend patterns, NEM exhibited an increasing tendency and SIM exhibited average results. A previous study that was carried out during 1987–2017 by Nisansala et al. [46] reported similar results for the NEM, SWM, and SIM seasons. Wickramagamage [47] also reported an increasing rainfall trend during the NEM season and decreasing trends in the SWM for Sri Lanka during 1981–2010. However, Nisansala et al. [46] and Wickramagamage [47] also showed different results compared with the present study at the annual and seasonal scales for rainfall trends by showing an increasing tendency. In the present study, the Dampahala station showed increasing trends for rainfall, while all the other stations showed decreasing trend patterns. Similar to the present study, contrasting directions of the magnitude of trends in nearby stations of the same basin were reported by Khaniya et al. [48] and Pawar and Rathnayake [49]. These contrasting results might have been because of local rainfall events. Mehta and Yadav [50] demonstrated that the magnitude of climate variability change across spatial scales. According to the results of the present study, the streamflow trend analysis did not show significant trends, except in December. However, non-significant increasing trends were demonstrated at the annual scale and the NEM and FIM, but not for the SWM SIM. Dinethra and Basnayake [51] showed that the discharge of the Nilwala River increased during 2004–2013. When considering the extreme rainfall indices, they also showed few significant trends. However, extreme rainfall indices trend patterns also showed similar contrasting results, especially for the Dampahala and Deniyaya stations. These contrasting results might have been due to variations in elevations, as explained by Bizuneh [52]. The NRB comprises lowlands and mountains. Due to the windward and leeward sides of the mountains, these types of contrasting results in the direction of rainfall trends can happen. This is because the windward side normally receives higher rainfall, while the leeward side of the mountain gets lower rainfall. Considering rainfall, extreme rainfall, and streamflow trend results, we concluded that rainfall was not only the influencing factor for the changes in streamflow patterns for the NRB. Other factors, such as the density of physical features, watershed characteristics, and vegetation cover, can be influential as well [2].

4. Conclusions

The main objective of this study was to analyze the trends that were present in the rainfall and streamflow records and to identify the correlation between the rainfall and streamflow over the Nilwala River Basin. Six rainfall stations and one hydrological gauge station were chosen based on the data availability. There was a considerably good correlation present between the rainfall and streamflow in the upper Nilwala Basin, indicating that rainfall was the main driver for the changes in the streamflow. This study showed that the NRB did not face extreme climatic events from 1990 to 2014. Variations in the topographical features in the basin might lead to contrasting results in rainfall trends within the NRB. Five out of six stations showed decreasing trends in rainfall, suggesting that, in general, rainfall had been decreasing during the 25 years between 1990 and 2014. The insignificant trends in rainfall and streamflow suggested that the climate and hydrologic regimes were not altered during this period. Future research is advocated for in the NRB considering that other possible factors, such as the impacts of land-use change, could also be influential.

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